Indian Journal of Biochemistry & Biophysics
Vol. 57, August 2020, pp. 449-457

Methane production enhancement and comparative study of biodegradation of some plants and animal wastes

Ezekoye Veronica[1]*, Peter Offor[2], Ofomatah Anthony[3], Agbogu Ada[4] & Ezekoye David[5]

[1]Natural Science Unit, School of General Studies; [2]Metallurgical and Materials Engineering Department;
[3]National Centre for Energy Research and Development; [4]Department of Physics and Astronomy; &
[5]Department of Civil Engineering, University of Nigeria, Nsukka

Received 09 March 2017; *revised 26 December 2019*

This study investigated the production of methane using various substrates. Plantain peels, pig dung, poultry droppings, walnut peels/plantain peels and cow blood/wheat waste were all co-digested, charged in digesters (A-E) and allowed to ferment anaerobically for forty-five (45) days within the mesophilic temperature range of 20.0-39.0°. Digester A contained 3.9 Kg of wheat waste/cow blood and 19.5 Kg of water in the ratio of 1.5 which gave a total gas yield of 22.5 L of biogas; B contained 7.8 Kg of walnut peels/plantain peels and 15.6 Kg of water in the ratio 1:2 which gave a total gas yield of 115.0 L; C contained 8 Kg of plantain peels and 16 Kg of water which yielded 133.0 L of biogas; D contained 8 Kg of pig dung mixed thoroughly with 16 Kg of water which gave a total of 321.0 L; and E contained 8 Kg of poultry droppings mixed with 16 Kg of water which yielded 168.5 L of biogas. From the cumulative comparison of the biogas yields of the samples, pig dung gave the highest yield of 321 L and cow blood/wheat husk produced the lowest yield of 22.5 L. Pig dung (animal waste) gave the highest total viable count (TVC) of 7×10^6 cfu/mL. The sludge contains NPK which is a good biofertilizer.

Keywords: Anaerobically, Cumulative comparison, Digesters, Mesophilic, Substrate

It is necessary to focus on basic and applied research in order to find the best ways and solutions to energy scarcity so as to promote the valorization of the generated waste from a huge number of sources either by manufacturing new products with high added value or producing energy[1]. Increasing population levels, a booming economy, rapid urbanization and the rise in community living standards have greatly accelerated the municipal solid waste generation rate in developing countries[2].The production of fruits and vegetable waste is also very high and is becoming source of concern in municipal landfills because of their high biodegradability[3]. The synthesis of biomass to produce energy is a growing trend worldwide as the quest for clean energy alternatives instead of the traditional fossil fuels intensifies[4]. Growing energy demand and the impacts of fossil fuel contribute towards the commercialization of biogas as a finite energy source. Organic waste materials are the major attraction for biogas production; even as biogas production through anaerobic digestion ensures alternative fuel, biofertilizer, electricity production, waste recycling, greenhouse gas reduction, and environmental protection[5,41]. Millions of homes in less-developed regions, including China and parts of Africa, are estimated to use household digesters as a renewable energy source [35].

Methane is the combustible fraction of biogas whereas relatively lower methane content of typical biogas in contrast to conventional energy sources is an added drawback that restrains the acceptance of biogas for commercial purposes[4]. However, ordinary waste materials or feedstock could not provide sufficient biogas[4]. The major aspect for sustainable feedstock utilization is united with the characteristics of the substrate. Substrate availability is another concern that has to be assured for commercialization of biogas in future[3]. In spite of this criterion animal manure was the most frequently used feedstock than agro industrial wastes until recent past. On the other hand, it may be due to the fact that manures possess low lignocelluloses content and can be effortlessly degradable by the microorganisms inhabited with it[4]. The accessibility of complex organic materials is a difficult task that requires further treatments to ensure absolute degradation and thereby biogas production[6].

---

*Correspondence:
E-mail: veronica.ezekoye@unn.edu.ng

The world is unavoidably faced with crises of fossil fuel shortage and environmental degradation as a result of growth in population, urbanization and industrialization[7]. Biogas is a mixture of gases evolved from the digestion process of organic matter by anaerobic bacteria at anaerobic conditions and many factors have been found that can control the efficiency of biogas production[8,38]. Most studies about biogas indicate that methane (CH_4) and carbon dioxide (CO_2) are the main components, where the ratio of methane ranged between 50 - 80% and the ratio of carbon dioxide range is 20 - 50% [42]. The carbon dioxide fraction reduces the calorific value of biogas [9]. Other components of biogas that may be found in small amounts (traces) are Hydrogen (H_2), Nitrogen (N_2), Hydrogen Sulfide (H_2S), Carbon monoxide (CO), Ammonia (NH_3), Oxygen (O_2) and water vapor (H_2O). Methane and carbon dioxide are odorless and colorless gases. Hydrogen sulfide is colorless but it has an odor of rotten eggs in addition to its toxicity[9].

Anaerobic bioreactors (ABs) have potential applications for rapid digestion of solid organic waste constituents to reduce the environmental load as compared to conventional sanitary landfills[10,11]. Bioreactor design has been found to exert a strong influence on the performance of a digester[12]. A variety of new bioreactor designs have been developed in recent years which facilitate a significantly higher rate of reaction for the treatment of waste[13-15]. According to Chandrasekhar and his co-workers, an anaerobic bioreactor should be designed in a way that allows a continuously high and sustainable organic load rate with short hydraulic retention time and has the ability to produce the maximum level of methane[16]. Anaerobic digestion (biogas technology) of organic wastes produces both biofertilizer and biogas[37]. Unlike composting, the digestion process retains and even improves the nutrient value of the original feed stock[17]. Many methods and technologies could be applied to treat organic wastes such as direct combustion, fermentation, gasification, pyrolysis, and anaerobic digestion[18,40]. The aim of the present study was to generate and compare the physicochemical characteristics of biogas produced by co-digesting walnut waste and plantain peels, wheat husk, and cow blood substrate mixture.

Materials and Methods

The materials used for this study include five fixed dome biodigesters of volume 30254.72 cm^3 (≈30 L), wheat husk (waste) and cow blood, pre-decayed walnut peels and plantain peels, pig dung; poultry droppings, weighing balance, pH paper, and electronic pH meter, plastic bowl and a 20 L gallon; gas hose, bamboo stick, and water. The batch operation method was used in this study.

Preparation of the samples

Solid and granular wastes like the walnut and plantain peels were first ground by mashing until a soft pulpy texture was obtained. The wastes were then mixed with water at specific ratios and fed separately into the digesters (A-E). Cow blood and wheat waste were mixed together and the combination mixed with water at a ratio of 1:5 and fed into digester A. Walnut and plantain peels were mixed with water at a ratio of 1:2 and fed into digester B. Plantain peels charged (independently) were mixed with water at a ratio of 1:2 and fed into digester C. Pig dung was mixed with water at a ratio of 1:2 and fed into digester D. Poultry droppings with water at a ratio of 1:2 were fed into digester E (Table 1).

Experiments A, B, C, D, and E were monitored for a period of 45 days until the biogas production rate became low. The records of volume and temperature were taken accordingly. A mercury-in-glass thermometer calibrated in centigrade from −10 to 110°C was used to measure both ambient and slurry temperatures. The volume of gas produced was obtained using the method of water displacement. Measurement of volume for each experiment was taken

Table 1 — Mixing ratio and the temperature of the samples

Wastes	Mixing ratio	Quantity of waste/water (Kg)	Ambient temp. range (°C)	Slurry temp. range (°C)	Volume of gas produced (L)
Pig dung(pd)	1:2	8:16	21.5-31.5	24.0-37.0	321.0
Poultry dropping(pod)	1:2	8:16	21.5-32.0	23.0-36.5	168.5
Plantain peel(pp)	1:2	8:16	21.5-31.5	24.0-38.8	131.0
Walnut/plantain(w/p)	1:2	7.8:15.6	22.0-34.5	24.0-38.8	115.0
Cow blood/wheat(b/w)	1:5	3.9:19.5	21.5-31.5	24.0-38.0	22.5

on a daily basis. For the measurement of pH, an electronic pH meter at the laboratory of the National Centre for Energy Research and Development was employed alongside a pH paper (for rough determination). Measurement was taken on a weekly basis. A Bunsen burner and a matchbox were used for flammability test. Flammable gas burned with a blue flame while non-flammable gas simply did not burn. The flammability was observed as shown (Table 2).

Qualitative analyses of the wastes

Proximate analysis for each of the samples was carried out in the laboratory section of the National Center for Energy Research, and development, University of Nigeria. Since the initial and final (0th & 45th day) samples from the digesters were collected and then evaluated for total solids, volatile solids, carbon, nitrogen, lignin, and cellulose content[5,10]. The common parameters such as pH and temperature of fresh substrate mixture and digested slurry were examined through the digital pH meter and thermometer. The total viable count determinations for microbes in each sample were carried out in the pharmaceutical laboratory of the University of Nigeria, Nsukka[39] (Tables 3-9).

Characteristics of the biogas produced

Each sample of biogas produced was analyzed using Orsat Apparatus. The measuring principle of Orsat Apparatus is the measurement of the reduction which occurs when individual constituents of gas are removed separately by absorption in liquid reagents (Table 10).

A gas compressor is a mechanical device that increases the pressure of a gas by reducing its volume.

Table 2 — Retention time and days of flammability

Wastes	Retention time(days)	Flammable time (days)	Volume of gas produced(L)
Pig dung(pd)	45	8	321.0
Poultry dropping(pod)	45	9	168.5
Plantain peel(pp)	45	6	131.0
Walnut/plantain(w/p)	45	12	115.0
Cow blood/wheat(b/w)	45	-	22.5

Table3 — Proximate Analysis for Pig dung and Poultry dropping

Parameter	Pig dung		Poultry dropping	
	Before digestion (%)	After digestion (%)	Before digestion (%)	After digestion (%)
Nitrogen	0.61	3.06	1.99	2.25
carbon content	1.88	1.63	14.12	8.27
pH	6.00	7.61	8.10	8.60
Ash	2.35	6.00	4.90	1.90
moisture	88.46	78.20	69.80	87.40
phosphorus	0.08	0.54	0.31	0.90
Volatile solid	71.65	69.35	81.11	80.35
Total solid	96.45	78.20	87.40	70.79
potassium	0.65	0.76	0.43	0.6

Table 4 — Proximate analyses of walnut/plantain and plantain peels

Parameter	Walnut/plantain (w/p)		Plantain peel (pp)	
	Before digestion (%)	After digestion (%)	Before digestion (%)	After digestion (%)
Nitrogen	0.13	0.27	0.07	0.17
carbon content	6.98	4.92	4.83	2.50
pH	8.33	7.20	9.48	9.00
Ash	0.79	0.38	0.86	0.60
moisture	94.00	96.36	94.34	96.55
Volatile solid	1.00	0.42	0.71	0.27
Total solid	1.28	0.60	0.92	0.40
fiber	2.83	1.35	3.07	1.79
protein	1.67	0.78	1.05	0.44
Fat	0.04	0.03	0.04	0.01

Table 5 — Characteristics of the five wastes used during the experimental study

Wastes	Total solid (%)	Volatile solid (%)	Total carbon (%)	Total nitrogen (%)	C/N ratio
Pig dung (pd)	78.20	69.35	10.63	3.06	3.47
Poultry dropping (pod)	70.79	80.35	14.12	1.99	7.09
Plantain peel (pp)	0.92	0.71	4.83	0.17	2.84
Walnut/plantain (w/p)	1.28	1.00	6.98	0.27	2.59
Cow blood/wheat (b/w)	0.92	0.75	5.10	0.17	3.80

Table 6 — Total viable count determination for bacteria

Wastes	Mean drop count	Dilution factor	Vol./drop (mL)	Total viable count (cfu/mL)
Pig dung (pd)	11	10^2	0.015	7×10^6
Poultry dropping (pod)	15	10^2	0.015	1×10^7
Plantain peel (pp)	11	10^{-4}	0.02	5.5×10^6
Walnut/plantain (w/p)	5	10^{-4}	0.02	2.5×10^6
Cow blood/wheat (b/w)	9	10^{-4}	0.02	4.5×10^6

Table 7 — Total viable count determination for fungi

Wastes	Mean drop count	Dilution factor	Vol./drop (mL)	Total viable count (cfu/mL)
Pig dung (pd)	None	None	None	None
Poultry dropping (pod)	none	None	None	None
Plantain peel (pp)	*Aspergillaus niger*	*Aspergillaus niger*	*Aspergillaus niger*	*Aspergillaus niger*
Walnut/plantain (w/p)	none	None	None	None
Cow blood/wheat (b/w)	none	None	None	None

Table 8 — Organism isolated from the three samples

Wastes	Total viable count (cfu/mL)	Grams character	Organism isolated
Cow blood/wheat (b/w)	4.5	Positive	*Sarcinaintea*
		Negative	*Salmonella* spp
		Positive	*Bacillus cerus*
		Negative	*E. coli*
Walnut/plantain (w/p)	2.5	Negative	*E.coli*
		Positive	*Bacillus subtilis*
		Negative	*Salmonella* spp
Plantain peel (pp)	5.5	Positive	*Bacillus subtilis*
		Negative	*E. coli*
		-	*Aspergillus niger*
		Negative	*Salmonella* s[pp

The capacity of the compressor used was 1/5 horsepower. Each cylinder was able to compress biogas to 1.2 bars of pressure.

Results and Discussion

The daily ambient temperature and slurry temperature for the five different wastes were shown in (Figs. 1A & B) while the daily volume of the gas produced versus retention time (Fig. 2). Walnut husk with Plantain peels recorded the highest temperature range of 22.0-34.5°C and the five wastes produced biogas within the mesophilic range of temperature[9] (Evans, 2016), walnut/plantain (w/p) and Plantain peels (pp) recorded the highest slurry temperature range of 24.0 - 38.8°C. These ranges of temperature favour the mesophilic bacteria and all the samples in the digesters were agitated twice per day to achieve degradation.

Table 9 — Summary of the organism(s) isolated from the three samples

Samples	Organism isolated	Type of organism	Gram characteristics
A_1	*Sarcinaintea*	Bacteria	+ve
A_2	*Salmonella* spp	Bacteria	-ve
A_3	*Bacillus cerus*	Bacteria	+ve
A_4	*E. coli*	Bacteria	-ve
B_1	*E. coli*	Bacteria	-ve
B_2	*Bacillus subtilis*	Bacteria	+ve
B_3	*Salmonella* spp	Bacteria	-ve
C_1	*Bacillus subtilis*	Bacteria	+ve
C_2	*E. coli*	Bacteria	-ve
C_3	*Aspergillus niger*	Fungi	-ve
C_4	*Salmonella* spp	Bacteria	-ve

NB: A, B, C = Experiment A B C

Table 10 — Percentage of the component of biogas from five different wastes Using Orsat Apparatus

Wastes	Carbon dioxide (CO_2) (%)	Hydrogen sulphide H_2S (%)	Carbon monoxide (CO) (%)	Methane and other components (%)
Pig dung (pd)	24.9	1.2	3.7	70.2
Poultry dropping (pod)	17.4	0.3	0.5	81.9
Plantain peel (pp)	19.5	0.8	9.0	70.7
Walnut/plantain (w/p)	16.5	0.9	0.3	82.3
Cow blood/wheat (b/w)	-	-	-	-

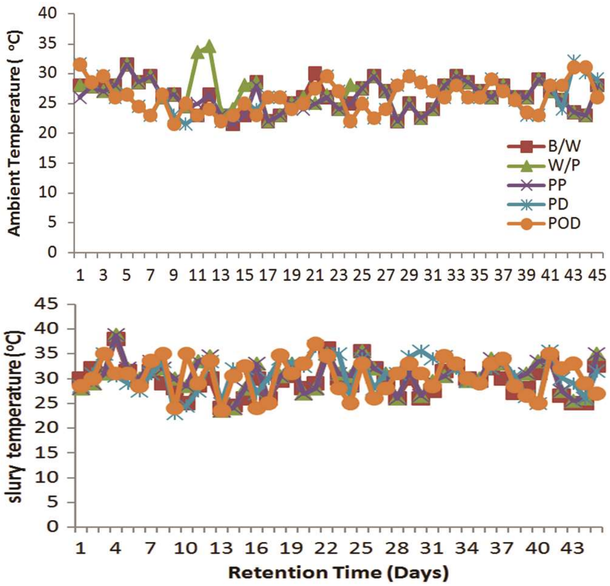

Fig. 1 — Change in (A) Ambient Temperature; and (B) Slurry temperature during Fermentation

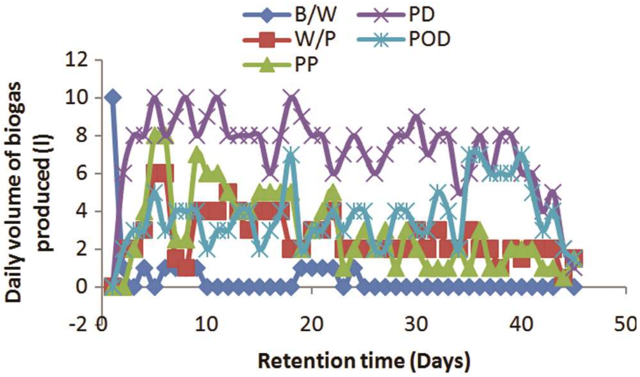

Fig. 2 — Volume of gas produced by five wastes during fermentation

The daily volumes of biogas yield of the five different wastes were shown in (Fig. 2). The curves show that the pig dung generated the highest gas from the first day to the 45th day. It was followed by poultry droppings which produced the highest between 20th and 43rd days. Cow blood/wheat husk produced the highest gas on the 2nd day of digestion. On the 3rd to 10th days and the 20th to 25th days it produces about 1.5 L of gas. On the other days, it did not produce any gas and its gas never became combustible, it was discovered that cow blood is not a good inoculum and it contains lignin[5]. Walnut husk with Plantain peels produced the highest gas on the 8th day and became combustible on the 12th day. The biogas produced burned with a blue flame and has the highest calorific value. Co-digesting walnut and plantain gave low gas yield than the independently charged plantain peels. Apart from Cow blood/wheat husk which did no yield biogas within the period of study, and the order of gas yield was pig dung>poultry droppings>Walnut/plantain>Plantain peels.

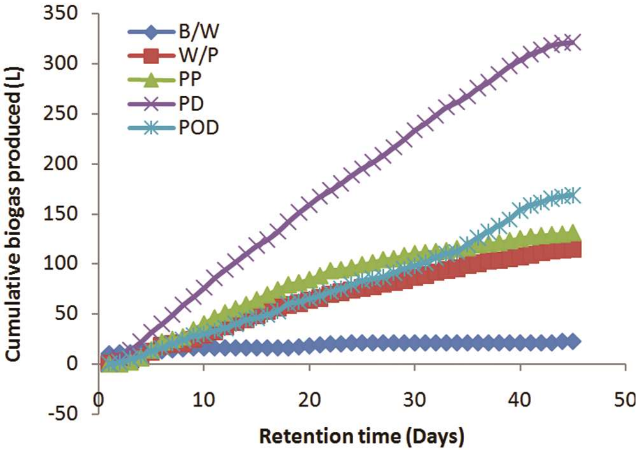

Fig. 3 — Cumulative gas produced by five different wastes

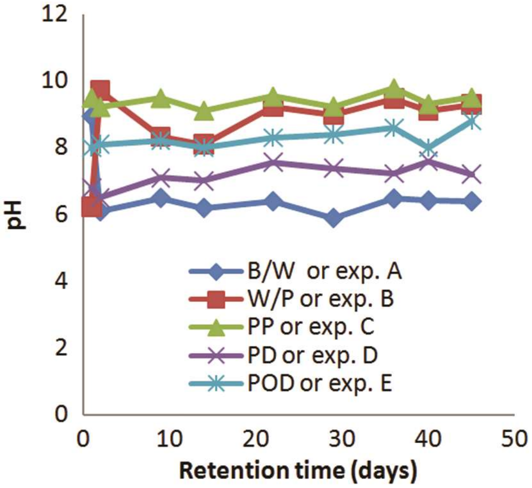

Fig. 4 — Change in pH during Fermentation

On the other hand, the pig dung slurry produced combustible gas on the 8th day and Plantain peels on the 6th day (Table 2). The cumulative biogas yields of the sample are compared in (Fig. 3). The pig dung gave the highest yield of 321 L and Cow blood/wheat husk produced the lowest yield of 22.5 L. From (Table 3) and 4 the pH values of the four samples range from 6 to 9. Pig dung and poultry droppings produced a combustible gas at the pH range of 7.71 and 8.60. While walnut/plantain and plantain peels produced a combustible gas at the pH range of 7.20 and 9.00.

For optimum functioning, the anaerobic microorganisms require a neutral environment. Figure 4 shows the change in pH during fermentation. A range of pH values suitable for anaerobic digestion has been reported by various researchers, but the optimal pH for methanogenesis has been found to be around 7.0. It was showed that the most favorable range of pH to attain maximal biogas yield in anaerobic digestion is 6.5–7.5. The moisture content of all the samples ranges from 69.80% to 96.55%. High moisture contents usually facilitate the anaerobic digestion; however, it is difficult to maintain the same availability of water throughout the digestion cycle. It has been reported by[19, 20] that the highest methane production rates occur at 60–80%. They found that the onset of the methanogenic phase took place around day 70 in both cases, at 70% and 80% moisture. The carbon/nitrogen (C/N) ratio of the samples used in this study runs from 2.59 to 7.09.

The rate of anaerobic digestion is strongly affected by the type, availability, and complexity of the substrate which is in line with the research [21,22]. Different types of carbon sources support different groups of microbes[9]. Before starting a digestion process, the substrate must be characterized for carbohydrate, lipid, protein, and fiber contents[23]. In addition, the substrate should also be characterized by the quantity of methane that can potentially be produced under anaerobic conditions. Carbohydrates are considered the most important organic component of municipal solid waste for biogas production[9]. Nitrogen is essential for protein synthesis and primarily required as a nutrient by the microorganisms in anaerobic digestion[24]. Nitrogenous compounds in the organic waste are usually proteins which are converted to ammonium by anaerobic digestion[25]. In the form of ammonium, nitrogen contributes to the stabilization of the pH value in the bioreactor where the process is taking place. Microorganisms assimilate ammonium for the production of new cell mass. The C/N ratio in the organic material plays a crucial role in anaerobic digestion.

The unbalanced nutrients are regarded as an important factor limiting anaerobic digestion of organic wastes. For the improvement of nutrition and C/N ratios, the co-digestion of organic mixtures is employed [26]. Both acid and methane forming bacteria could not survive the pH values of 4 and 10. The different bacteria and fungi that aided degradation of substrate were listed in (Tables 6-9). The total viable count determination for bacteria of the five samples runs from 7 × 10^6 cfu/mL to 1 × 10^7 cfu/mL. The anaerobic digestion process can be catalyzed by a variety of microorganisms that convert complex macromolecules into low molecular weight compounds. An inoculums source is crucial for the optimization of the waste/inoculum ratio[27,28]. Wet (40-95%) organic materials with low lignin and cellulose content are generally suitable for anaerobic digestion[37]. A wide variety of microbial communities have been reported to be involved in the anaerobic decomposition process[29] reported that organic material is most likely decomposed by heterotrophic microorganisms while[30] reported that Clostridium species are most common among the degraders under anaerobic condition.

Different wastes were used in feeding the digester in order to find out which one produced more biogas. It was found that organic waste which is easily digestible produced more gas. Based on recent research materials, high lignocellulose produces less amount of gas[20]. Carbon, which constitutes the basic frame of all organic substrates provides energy used by the microbes for their living activities and is the source for the formation of biogas. In biogas production, nitrogen provides methanogenic bacteria with ammonia, which is the source of nitrogen for the composition of living matter of new cells[33]. The carbon/nitrogen ratios for all the wastes were listed in (Table 6). The ideal carbon to nitrogen ratio for anaerobic digestion is between 20:1 and 30:1 according to studies of Ogbene, Andrew & Sunday[36].

The slurry should not be too thick nor too dilute. In this experiment, the dilution ratios used for all the wastes were recorded in (Table 1). Enough microbes were present in the digester to fasten the fermentation process. This was shown in the total viable count determination in (Tables 6 & 7). Gas production was found to be low at pH 4 and 9. The reason for the low pH values at the beginning of digestion was attributed to the fact that initially the acid- forming bacteria will be breaking down the organic matter and producing volatile fatty acids. As a result, the general acidity of the digesting material will increase and the pH will fall below neutral this is in agreement with work done by Lee *et al*[31]. It was after week 2 of fermentation that the acid formers were most probably replaced by the methane forming bacteria and there is a gradual rise in the pH to 7.40 as shown in (Fig. 4).

Meanwhile, anaerobic degradation efficiency strictly depends on the characteristics of the samples used for charging the digester. Stirring also is necessary for increased gas production. When the slurry was stirred once in a day, there was an increase in gas production. There was also a drop in gas production when stirring was completely omitted due to scum formation. After the analysis of the slurry, it was discovered that there was an increase in the percentage content of nitrogen, potassium, protein, and phosphorus after digestion. This shows that the sludge is a better fertilizer to the soil (Table 3)[32,33]. The sludge is a potential organic manure[34].

Table 2 shows that plantain peels gave the shortest flammability time of 6days followed by pig dung (8 days), poultry droppings (9 days), walnut husk/ plantain peels (12 days), while cow blood/wheat chaff was not flammable within the period of study. The gas analyser and Orsat apparatus were used for the analysis of the composition of biogas produced (Table 10). The methane content of the biogas produced was in this order: the highest - walnut husk/ plantain peels, next, poultry droppings, then plantain peels, and the least, pig dung.

Conclusion

The study revealed that animal wastes (pig dung and poultry dropping) anaerobically digested have higher yields of biogas in comparison with plant wastes (plantain peels and walnut husk/plantain peels). On the other hand, walnut husk/plantain peels yielded biogas faster than pig dung while pig dung produced a larger amount of biogas. Cow blood/wheat husk does not have enough carbon and nitrogen elements that meet the C/N ratio for optimum biogas yield. It was further observed that pig dung and poultry droppings were found to be better bio-fertilizer because of the presence of a higher volume of NPK in the digested wastes compared with those of walnut husk/plantain peels. Furthermore, walnut husk/plantain peels showed the highest yield for methane production, meanwhile, *Aspergillus nigers* were the only microbial (fungi) isolated in plantains peels while *Garcinia tea*, *Salmonella* spp, *E. coli*, and *Bacillus cereus* were the microorganisms associated with fermentation of the wastes.

Conflict of interest

All authors declare no conflict of interest.

Acknowledgment

Authors acknowledged the National Center for Energy Research and Development, University of Nigeria Nsukka, for their assistance with the Laboratory work.

References

1 Maria L, Waste Management and Symbiosis for Waste Valorization. *Waste Biomass Valor*, 6 (2015) 623.

2 Ganesh KN, Pandey SD, Mallick S, Ghosh SK, Pramanik P & Ghosh AS, Thiol stabilized copper nanoparticles exert antimicrobial properties by preventing cell division in *Escherichia coli*. *Indian J Biochem Biophys*, 57 (2020) 151.

3 Azeem K, Muhammad A, Muzammil A, Tariq M & Lorna D, The anaerobic digestion of solid organic waste. *Waste Manag*, 1 (2011) 1737

4 Kigozi R, Aboyade A, & Muzenda E, Biogas production using the organic fraction of muncipal solid waste as feedstock. *Int J Res Chem Mettall Civil Engg*, 1 (2011) 107.

5 Divya D, Gopinath LR, Indran S & Merlin CP, Enchancement of biogas production through sustainable feedstock utilization by co-digestion. *Int J Plant Animal Environ Sci*, 5 (2015) 88.

6 Roland W, Etelka K, Gergely M, Zoltan B, Gabor R & Kornel LK, Characterisics of biogas producing microbial community by short-read next generation DNA sequencing. *Biotechnol Biofuels*, 5 (2012) 41.

7 Nuttall WJ & Manz, DL, A new energy security paradigm for the twenty-first century. *Technol Forecast Soc*, 75 (2008) 1247.

8 Srichat A, Suntivarakorn R & Kamwilaisak K, Impact of Organic Loading Rates of Waste Water from Broilers Manure on CSTR Biogas System. *J SciInd Res*, 76 (2017) 588.

9 Sovik D & Ghangrekar MM, Value Added Product Recovery and Carbon Dioxide Sequestration from Biogas Using Microbial Electrosynthesis. *Indian J Exp Biol*, 56 (2018) 470.

10 Mario G, Stefano D, Lucia R & Sergio S, Case study of an MBT plant producing SRF for cement kiln co-combustion, coupled with a bioreactor landfill for process residues. *Waste Manag*, 47 (2016) 267-275.

11 Lesteur M, Bellon-Maurel V, Gonzalez C, Latrille E, Roger JM, Junqua G & Steyer JP, Alternative methods for determining anaerobic biodegradability: A Review. *Process Biochem*, 45 (2010) 431.

12 Giani H, Borchers B, Kaufeld S, Feil A & Pretz T, Fine grain separation for the production of biomass fuel from mixed municipal solid waste. *Waste Manag*, 47 (2016) 174.

13 Alexis MT, & James RM, Sustainable recycling of municipal solid waste in developing countries. *Waste Manag*, 29 (2009) 915.

14 Kodwo M, Kwasi O, Zsofia K, Bernard F & Moses Y, Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Manag*, 46 (2015) 15.

15 Francesca G, Luca A & Raffaello C, Food waste generation and industrial uses: A review. *Waste Manag*, 45 (2015) 32.

16 Chandrasekhar K, Amulya K & Venkata SM, Solid phase bio-electro fermentation of food waste to harvest value-added products associated with waste remediation. *Waste Manag*, 45 (2015) 57.

17 Hannan MA, Abdulla AM, Acini H, Hassan B & Bengum RA, A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges. *Waste Manag*, 43 (2015) 509.

18 Rachel EM & Khosrow F, Systems approaches to integrated solid waste management in developing countries. *Waste Manag*, 33 (2013) 988.

19 Lymperatou A, Gavala HN, Esbensen KH & Skiadas IV, AMMONOX: Ammonia for enhancing biogas yield and reducing NO_X-Analysis of effects of aqueous ammonia soaking on manure fibers. *Waste Biomass Valor*, 6 (2015) 49.

20 Bouallagui H, Cheikh RB, Marouani L & Hamdi M, Mesophilic biogasproduction from fruit and vegetable waste in tubular digester. *Bioresour Technol*, 86 (2003) 85.

21 Wang J, Xiaoguang L, Sun J, Peng M & Shi P, Proteomic changes in response to lipin1 overexpression in 293T human renal epithelial cells. *Indian J Biochem Biophys*, 56 (2019) 466.

22 Geethanjali S & Subash A, Isolation and purification of protease from *Labeo rohita* viscera. *Indian J Biochem Biophys*, 55 (2018) 2220.

23 Zhao Y, Wang A & Ren N, Effect of carbon sources on sulfidogenic bacterial communities during the starting-up of acidogenic sulfate-reducing bioreactors. *Bioresour Technol*, 101 (2010) 2952.

24 Dong L, Zhenhong Y, Yongming S & Xiaoying KZ, Hydrogen production characteristics of organic fraction of municipal solid wastes by anaerobic mixed culture fermentation. *Int J Hydr Energy*, 34 (2009) 812.

25 Subudhi S, Sethi D & Pattanayak SK, Characterization of *Rhizobium* sp (SAR-5) isolated from root nodule of *Acacia mangium* L. *Indian J Biochem Biophys*, 57 (2020) 327.

26 Sawayama S, Tada C, Tsukahara K & Yagishita T, Effect of ammonium addition on methanogenic community in a fluidized bed anaerobic digestion. *J Biosci Bioeng*, 97 (2004) 65.

27 Cuetos MJ, Gomez X, Otero M & Moran A, Anaerobic digestion of solid slaughterhouse waste (SHW) at laboratory scale: influence of co-digestion with the organic fraction of municipal solid waste (OFMSW). *Biochem Engg J*, 40 (2008) 99.

28 Lopes WS, Leite VD & Prasad S, Influence of inoculum on performance of anaerobic reactors for treating municipal solid waste. *Bioresour Technol*, 94 (2004) 261.

29 Forster-Carneiro T, Pérez M, Romero LI & Sales D, Dry-thermophilic anaerobic digestion of organic fraction of the municipal solid waste: focusing on the inoculum sources. *Bioresour Technol*, 98 (2007) 3195.

30 Fricke K, Santen H, Wallmann R, Huttner A & Dichtl N, Operating problems in anaerobic digestion plants resulting from nitrogen in MSW. *Waste Manag*, 27 (2007) 30.

31 Lee J, Song J & Hwang S, Effects of acid pre-treatment on bio hydrogen production and microbial communities during dark fermentation. *Bioresour Technol*, 100 (2009) 1491.

32 Sanchez E, Borja R, Weiland P, Travieso L & Martin A, Effect of Temperature and pH on the kinetics of methane production, organic nitrogen and phosphorus removal in the batch anaerobic digestion process of cattle manure. *J Bioproc and Biosyst Eng*, 22 (2007) 1.

33 Chemical Land, 21 NPK, fertilizer E:/NPK (fertilizer) mht. (2006).

34 Sharma S, Arora K & Sharma A, Comparative Evaluation of Chemicals and Botanicals Based Dehydration of Biogas Slurry. *J Sci Ind Res*, 75 (2016) 115.

35 Christopher A & Badurek, Biogas Encyclopaedia Britannica. (Encyclopaedia Britannica, Inc.) 2020.

36 Ogbene G, Andrew C & Sunday A, Feasibility study of biogas energy generation from refuse dump in a community-based distribution in Nigeria. *Int J Low-Carbon Tec*, 14 (2019) 227.

37 Abdeen O, Biogas technology for sustainable energy generation: development and perspectives. *MOJ App Bionics Biomech*, 4 (2017) 137.

38 Srichat A, Suntivarakorn R & Kamwilaisak K, Impact of organic loading rates of waste water from broilers' Manure on CSTR biogas system. *J Sci Ind Res*, 9 (2017) 588.

39 Das S & Ghangrekar M, Value added product recovery and carbon dioxidesequestration from biogas using microbial electrosynthesis. *Indian J Exp Biol*, 56 (2018) 470.

40 Jain K, Suryawanshi P & Chaudhari A, A Recovery of acerbic anaerobic digester for biogas production from pomegranate shells using organic loading approach. *Indian J Biochem Biophys*, 57 (2020) 86.

41 Khan A, Naz S, Ahmed M & Yasmeen K, Green and renewable electricity generation from wastewater inoculated with seaweeds extract using novel tool of bioreactors. *Indian J Mar Sci*, 47 (2018) 1081.

42 Ghosalkar A & Kumbhar P, Methanol and DME Economy in India. *Sci Rep*, 56 (2019) 19.